# AFRL Solid Propellant Laboratory Explosive Siting and Renovation Lessons Learned

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## ABSTRACT

The Solid Propellant Mix Laboratory, located at Edwards Air Force Base (EAFB) California underwent a major renovation to address facility and personnel protection deficiencies identified during a structural and hazard analysis performed for explosive re-siting of the facility. This paper documents the re-siting and renovation approach/efforts performed by AFRL personnel, consultants and contractors from 2006 to 2010, and the lessons learned that may help other organizations faced with re-siting and renovating explosive facilities.

## INTRODUCTION

In support of their mission to provide the United States Air Force with advanced rocket propulsion technologies, the Air Force Research Laboratory (AFRL) Propulsion Directorate (RZ-West), located at EAFB routinely manufactures, tests and stores highly energetic and explosive materials that are utilized in liquid and solid propulsion systems. Many of these materials are manufactured, characterized and tested at RZ-West's Propellant laboratory Complex (Area 1-30A).

Area 1-30A contains over 30 facilities which support solid rocket propellant, ionic liquid monopropellant and energetic ingredient research and development activities. One of the main facilities of Area 1-30A is the Solid Propellant Mix Laboratory (Bldg 8473).

In 2006 the RZ-West Explosives Safety office started the process for re-siting several RZ-West explosive facilities including Area 1-30A. The Safety office and RZ-West senior management were concerned that the once state-of-the-art Propellant Laboratory Complex was in need of significant renovation. Also, it was recognized that over the 21 year period since the last explosive siting, Area 1-30A was no longer compliant with DDESB's current requirements. To help ensure the explosive re-siting went smoothly, the following approach was implemented:

- Renovation projects were planned for the two main research facilities in Area 1-30A: Bldg 8473 and the Energetic Materials Research and Characterization Laboratory (Bldg 8475). The renovations included: new laboratory equipment, hoods, benches, cabinets, conductive floors and electrical upgrades in both facilities.
- Integrated Systems Analysts (ISA) Inc. was contracted to perform a comprehensive siting survey for each Area 1-30A explosive facility and provide consultation/support during the review process for each of the site plans.
- Applied Engineering Services (AES) Inc. was contracted to perform a detailed structural, blast, thermal and fragment hazard analysis for Bldg 8473 because this facility was determined to be the highest risk location due to the explosive operations conducted in cells 1-11 and specifically, the remote operations conducted in cells 2-5.

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14. ABSTRACT
**The Solid Propellant Mix Laboratory, located at Edwards Air Force Base (EAFB) California underwent a major renovation to address facility and personnel protection deficiencies identified during a structural and hazard analysis performed for explosive re-siting of the facility. This paper documents the re-siting and renovation approach/efforts performed by AFRL personnel, consultants and contractors from 2006 to 2010, and the lessons learned that may help other organizations faced with re-siting and renovating explosive facilities.**

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- A new Area 1-30A Operations Manager was assigned by the Space and Missile Propulsion Division (RZS) and the Propellants Branch (RZSP) to interface with the RZ-West Safety office, ISA, AES and the renovation contractors and support personnel to provide coordination, guidance and review of all efforts.

The area wide siting survey identified several findings that would need to be addressed such as: non-compliant equipment, electrical wiring/fixtures, lightning protection systems (LPS), transient voltage surge suppressors **(**TVSS), quantity distance (QD) violations and personnel protection deficiencies for some operations.

The structural, blast, thermal and fragment hazard analysis for Bldg 8473 identified three main categories of potential issues that would need to be addressed: wall failure, spalling/breaching of the wall and fragments exiting the cells.

As a result of the above listed findings, the renovation projects were focused to:

- Mitigate all of the findings
- Provide Area 1-30A researchers with facilities and equipment that are fully compliant with all regulatory requirements and provide the utmost in personal protection
- Provide Area 1-30A researchers with state-of-the art sustainable facilities and equipment

Although all of the explosive facilities in Area 1-30A went through re-siting, and the main operational locations underwent renovations, this paper focuses on the re-siting and renovation efforts for the Solid Propellant Mix Laboratory (Bldg 8473). The intent of this paper is to document the re-siting and renovation approach/efforts performed by AFRL personnel, consultants and contractors and the lessons learned that may help other organizations faced with re-siting and renovating explosive facilities.

## BACKGROUND

Building 8473 was built in 1960 and consisted of six reinforced concrete cells with explosion-resistant viewing windows, blow-off roof and blow-out back wall. In 1965, an additional five reinforced concrete cells with explosion-resistant viewing windows, reinforced concrete ceilings and blow-out back walls were added to increase Area 1-30A's testing capabilities.

The last time Bldg 8473 was re-sited was 1985, and at that time, the facility complied with all Department of Defense Explosive Safety Board (DDESB) requirements for an explosives operational facility. However, as previously stated, the Safety office and RZ-West senior management were concerned that the Solid Propellant Mix Laboratory no longer complied with DDESB's current (2006) requirements. To ensure the explosive re-siting of Bldg 8473 went smoothly, the following measures were taken:

- Renovation projects were started to bring the facility into compliance with current DoD explosive facility requirements.[1-3] The renovations included: facility upgrades to increase protection of personnel, new laboratory equipment, hoods, benches, cabinets, conductive floors and electrical upgrades.
- Integrated Systems Analysts (ISA) Inc. performed a comprehensive siting survey for Bldg 8473 and provided consultation/support during the siting review process.
- Applied Engineering Services (AES) Inc. performed a detailed structural, blast, thermal and fragment hazard analysis for Bldg 8473 due to the increased risk of the remote operations conducted in cells 2-5.

- The Area 1-30A Operations Manager interfaced with the RZ-West Safety office, ISA, AES and the renovation contractors and support personnel to provide coordination, guidance and review of all efforts.

**Bldg 8473 Pre-Renovation Layout and Operations**

Before the renovation, Bldg 8473 consisted of eleven reinforced concrete cells with blow-out rear walls, explosion resistant windows and remote manipulators (Cells: 1-4, 8, 9 and 11). The basic operations consisted of: mixing, casting and curing of high energy solid propellants. Remote operations were performed behind blast walls in the hallways while looking through explosion resistant glass windows. The basic layout is shown in Figure 1.

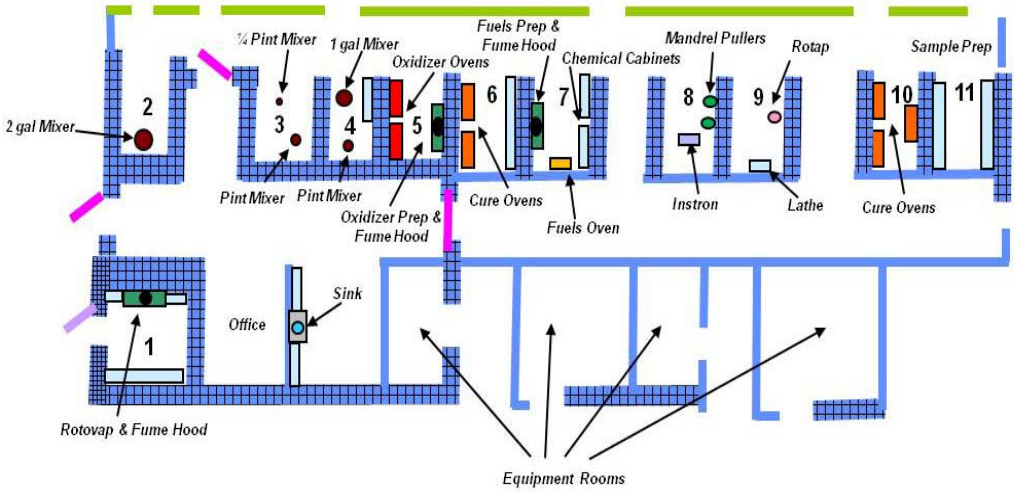


**Figure 1. Bldg 8473 Pre-Renovation Layout**

The specific operations by cell are listed below:

***Cell 1.***

Preparation and conditioning of propellant ingredients, such as solid propellant binders and energetic plasticizers. The cell contained a fume hood, explosion resistant window, eyewash station, safety shower and an AMF remote mechanical manipulator arm.

***Cell 2.***

Solid propellant mixing and casting. The cell contained a Baker Perkins two-gallon explosive rated planetary mixer and associated casting equipment. In addition, it contained two explosion resistant windows, an electronic scale for weighing propellant ingredients and an AMF remote mechanical manipulator arm.

***Cell 3.***

Low humidity solid propellant mixing and casting. Cell 3 contained a humidity controlled chamber that housed a Baker Perkins one-pint and quarter-pint explosive rated planetary mixer and associated casting equipment. In addition, it contained two explosion resistant windows, an AMF remote mechanical manipulator arm and an electronic scale for weighing propellant ingredients.

***Cell 4.***

Solid propellant mixing and casting. The cell contained a Baker Perkins one-pint and one-gallon explosive rated planetary mixer and associated casting equipment. In addition, it contained one explosion resistant window, an AMF remote mechanical manipulator arm and an electronic scale for weighing propellant ingredients

***Cell 5.***

Oxidizer preparation. The cell contained a fume hood and oven. In addition, it contained one explosion resistant window and three electronic scales for weighing propellant ingredients.

***Cell 6.***

Propellant curing. The cell contained a 30 cu-ft explosives rated cure oven and one explosion resistant window.

***Cell 7.***

Fuel preparation. The cell contained a fume hood and fuels oven. In addition, it contained one explosion resistant window and an electronic scale for weighing propellant ingredients.

***Cell 8.***

Mandrel removal, particle size segregation and high rate tensile tester. The cell contained: two hydraulically operated mandrel pullers, an Instron high rate uniaxial tensile tester, one explosion resistant window and two AMF remote mechanical manipulator arms.

***Cell 9.***

Solid motor trimming cell. The cell contained a remotely operated explosives rated lathe, two AMF remote mechanical manipulator arms, a Ro-Tap® sieve shaker, and one explosion resistant window.

***Cell 10.***

Propellant curing. The cell contained three explosives rated cure ovens and one explosion resistant window.

***Cell 11.***

Test sample preparation cell. The cell contained three work benches, an electronic scale for weighing samples, one explosion resistant window and two AMF remote mechanical manipulator arms.

## DISCUSSION

### Bldg 8473 Pre-Renovation Safety Issues

Some of the Bldg 8473 issues identified by RZ-West ground and explosives safety included: lack of grounding wires in the facility's electrical circuits, no ground fault interrupter (GFI) plugs or circuits for fixtures near sinks, non-compliant electrical fixtures, non-compliant LPS, no TVSS, damaged conductive flooring, roof leaks and potential lead and asbestos exposure for personnel.

The mitigations for all issues would be addressed by the renovation projects, increased oversight through a full-time operations manager and periodic review by PR-West senior managers.

**Integrated Systems Analysts (ISA) Inc. Siting Survey**

The siting survey performed by ISA for Bldg 8473 was done in conjunction with the Applied Engineering Services (AES) Inc. structural, blast, thermal and fragment hazard analysis to determine the appropriate siting values based on the structural and hazard analysis of the facility in addition to QD calculations.

Due to the R&D nature of the operations in Bldg 8473, it is standard practice to treat all explosive materials as HD 1.1 unless they have an approved interim hazard classification (IHC) or final hazard classification (FHC); therefore, ISA was asked to site all of the 11cells of Bldg 8473 for HD 1.1 propellants. In addition, for high energy solid propellants, a TNT equivalence of 125% was used for all explosive quantity assessments based on past studies with high energy solid propellants. [4]

The siting survey confirmed the facility and non-facility issues identified by RZ-West ground and explosives safety and determined that the explosive quantities would need to be reduced for many of the cells in the facility. The old site plan for Bldg 8473 allowed for explosive limits of up to 650 pounds of HD 1.1 materials for the entire building. The new site plan explosive limits would be reduced to approximately 426 pounds of HD 1.1 materials for the entire building.

The greatest reduction in Bldg 8473 explosive quantities was for Cell 1. The old site plan for Cell 1 allowed for explosive limits of up to 25 pounds of HD 1.1 materials. The survey determined that a maximum quantity of two pounds of HD 1.1 materials could be sited based on the potential to throw fragments into the Area 1-30A office building (Bldg 8483).

As part of the planned Bldg 8473 renovation effort, a 5-gallon Baker Perkins mixer was going to be added to Cell 2 that would increase the production capability from 33 pounds of solid propellant for the 2-gallon mixer to 90 pounds. ISA was asked to site Cell 2 for 90 pounds of HD 1.1 solid propellant and would be contingent upon the results of the AES structural, blast, thermal and fragment hazard analysis. This would be the largest quantity sited for the eleven cells in Bldg 8473. The HD 1.1 explosive amounts proposed for each cell are shown in Table 1.

| Cell | HD 1.1 Explosive Quantities (lbs) |
|---|---|
| 1 | 2 |
| 2 | 90 |
| 3 | 1.25 |
| 4 | 15 |
| 5 | 10 |
| 6 | 66 |
| 7 | 13 |
| 8 | 60 |
| 9 | 68 |
| 10 | 66 |
| 11 | 35 |

**Table 1. Explosive Amounts Proposed For Each Cell**

## AES Structural, Blast, Thermal and Fragment Hazard Analysis

As stated previously, the detailed structural, blast, thermal and fragment hazard analysis AES performed for Bldg 8473 was primarily due to the increased risk of the remote operations conducted in cells 2-5. However, it was discovered early into the siting survey that by conducting the AES analysis in conjunction with the ISA siting survey and the renovation effort, that all three efforts were complimentary and helped the siting process by:

- Providing an accurate structural and hazard analysis of the facility and equipment
- Providing an accurate hazard analysis of the planned operations
- Providing real time communications to resolve questions and issues
- Being able to mitigate facility/equipment issues through renovation efforts in real time

The AES analysis identified three main categories of potential issues that were associated with the explosive quantities requested: wall failure, spalling/breaching of the wall and fragments exiting the cells for some operations. There were issues identified for all eleven cells, however, the main issues were for Cell 2 and included:

- "The exterior side wall flexural requirement is not met for a 90-lb."
- "The shear capacity (diagonal tension) requirement is not met. Stirrups connecting the outer and inner sections of rebar are needed to meet this requirement, but were not included in the walls."
- "Spalling is predicted for the exterior side wall. This could reduce the wall thickness for fragment penetration, but there is sufficient thickness margin to prevent fragment penetration even if the concrete cover spalls off. The armor plating on the exterior faces of the front and interior side walls will prevent spalled fragments from becoming missiles."

Before Cell 2 could be sited for the 90 pounds of HD 1.1 propellants requested, the issues listed above would have to be addressed and adequate personnel protection provided to the building occupants.

## Naval Facilities Engineering Service Center Analysis

The Naval Facilities Engineering Service Center (NAVFAC ESC) was contracted to perform a supplemental engineering analysis of the issues AES identified for Cells 1-11 and provide recommendations for mitigating the deficiencies. NAVFAC ESC was selected to perform the tasks listed above based on the organization's reputation and experience with DoD explosive facilities.

On the preliminary assessment of Bldg 8473, the NAVFAC ESC structural engineer consultant met with the author to review the findings, the as-built drawings and survey the facility. One of the ideas proposed by the author was constructing a reinforced control room to protect personnel. The structural engineer consultant from NAVFAC ESC acknowledged the feasibility of this approach and identified two relatively low cost options for accomplishing this:

- The first option was to use Cell 1 because it had 16-inch thick reinforced concrete walls on three sides, a 10-inch thick reinforced concrete ceiling and it had a separate outside entrance.
- The second option was to use the old office area because it also had 16-inch thick reinforced concrete walls on three sides and a 10-inch thick reinforced concrete ceiling.

The second option was selected for the following reasons:

- Larger floor space
- Potential for increasing floor space including a restroom

- Internal entrance and the potential for a second outside entrance
- No loss of Cell 1 operations
- New Cell 1 lab equipment (hood, benches and cabinets) were already procured

The scope of the NAVFAC ESC contract was expanded to include a preliminary design of a hardened control room to protect personnel from blast and fragment hazards. The NAVFAC ESC design was for an 8-inch reinforced concrete wall composed of 4 ksi concrete with #4 bars spaced at 12 inches on center each way for each face, anchored into the existing reinforced concrete walls and a 3 psi rated blast door. The general layout of the control room proposed by NAVFAC ESC is shown in Figure 1. AES was tasked to provide a detailed design with inputs from NAVFAC ESC.

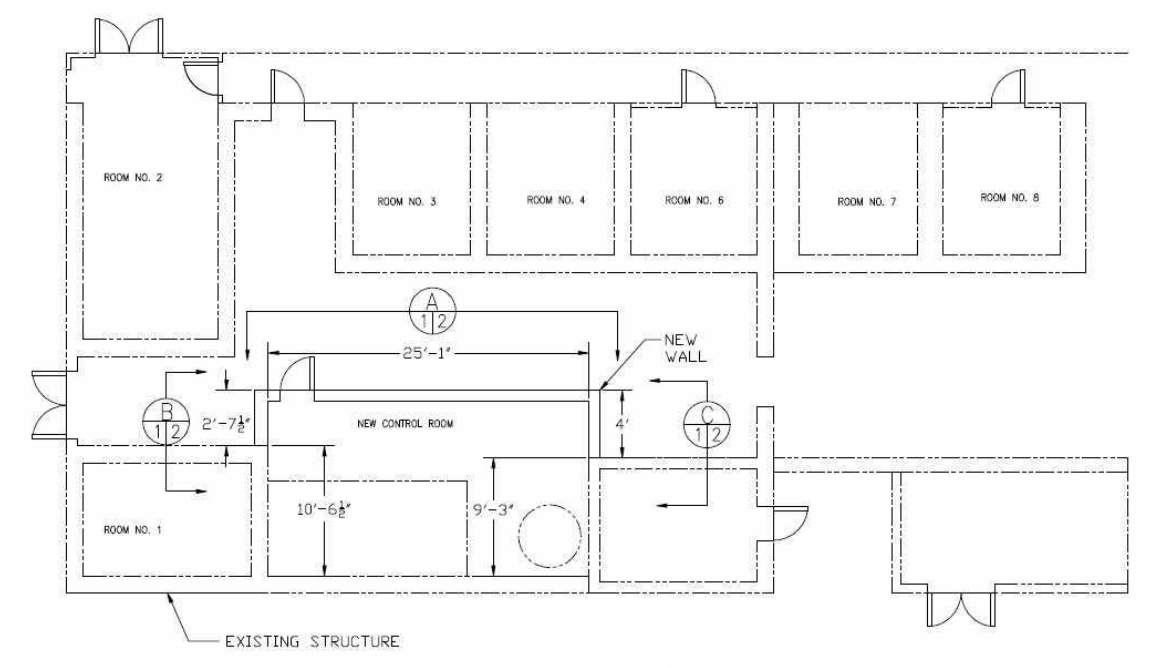


**Figure 1. Proposed layout of the new hardened control room**

The final AES design of the hardened control room and blast door were reviewed and endorsed by NAVFAC ESC "The hardened control room walls and blast door are designed to sufficiently resist any fragments and residual leakage blast pressure generated by an accidental explosion from one of the test cells. The blast door is the DB-200 Model from Protective Door Industries, has a minimum ultimate unit resistance of 3 psi and large ductility capabilities to attain large deflections, would be loaded in the seated direction, and has a custom door frame and anchors designed specifically to resist the blast loads and develop the full resistance of the door."

The NAVFAC ESC engineering analysis determined that all of the issues AES identified for Cells 1-11 would be mitigated by requiring personnel to conduct remote operations from inside the hardened control room with the blast door closed and all other building occupants to maintain minimum standoff distance from explosive operations.

"The analysis demonstrates that the construction of the hardened control room will provide equivalent personnel protection to occupants inside during all remotely controlled and hands-on operations in Building 8473. The blast door to the control room must be closed during all remotely controlled operations for equivalent personnel protection to be provided. If personnel are not inside the control room during an explosive operation, they must maintain the applicable minimum standoff distance from the cell that contains the explosives operation."

## Bldg 8473 Renovation Activities

The Bldg 8473 renovation activities consisted of the following main activities:

- Equipment removal
- Lead and asbestos abatement
- Construction
- New equipment installation
- Systems checks

The renovation began with AFRL personnel removing all of the equipment and hardware that was in contact with the floors, so the flooring contractors could remove the old conductive floor tiles. The same flooring contractor also performed the lead and asbestos abatement.

The construction activities consisted of:

- New conductive floors in the cells and connecting hallways used in explosive operations
- New roof
- Electrical and plumbing upgrades
- New control room and restroom
- Firex system upgrades

The new equipment installation activities consisted of:

- New laboratory furniture/equipment: (hoods, benches, cabinets, temperature circulators)
- New explosives rated cameras, ovens, environmental chambers and refrigerator
- New computers, monitors, data acquisition systems, programmable logic controllers (PLCs), remotely operated valves (ROVs) and variable frequency drives (VFDs)

The systems checks were performed for all the new and renovated equipment installed and the legacy equipment in Bldg 8473 including:

- Pneumatic, hydraulic and vacuum systems
- HVAC, laboratory hoods and equipment
- Electrical, instrumentation and plumbing
- New and refurbished mixer equipment/hardware
- New explosives rated cameras, ovens, environmental chambers and refrigerator
- New computers, monitors, data acquisition systems, PLCs, ROVs and VFDs

## Bldg 8473 Post-Renovation Layout and Operations

After the renovations, the remote operations (cells 2-5) will be controlled from the hardened control room using an Allen-Bradley programmable logic controller (PLC) system. The post-renovation layout showing the operations and HD 1.1 quantities for all cells is shown in figure 3.

The specific operations by cell are listed below:

***Cell 1.***

Preparation and conditioning of propellant ingredients, such as solid propellant binders and energetic plasticizers. The cell contains a fume hood, class 1/division 1 electrical fixtures, eyewash station, safety shower, two 6-liter reactors, a 1-liter rotary evaporator and two electronic scales for weighing propellant ingredients.

***Cell 2.***

Solid propellant mixing and casting. The cell contains a Baker Perkins two-gallon and five-gallon explosive rated planetary mixer, associated casting equipment and an electronic scale for weighing propellant ingredients.

***Cell 3.***

Solid propellant mixing and casting. Cell 3 contains a Baker Perkins one-pint and quarter-pint explosive rated planetary mixer, associated casting equipment and an electronic scale for weighing propellant ingredients.

***Cell 4.***

Solid propellant mixing and casting. The cell contains a Baker Perkins one-pint and one-gallon explosive rated planetary mixer, associated casting equipment and an electronic scale for weighing propellant ingredients

***Cell 5.***

Mandrel removal and particle size segregation. The cell contains: two hydraulically operated mandrel pullers, a Ro-Tap® sieve shaker and an electronic scale for weighing propellant ingredients.

***Cell 6.***

Propellant curing. The cell contains two 1.3 cu-ft explosives rated Friction-Aire® cure ovens.

***Cell 7.***

Fuel preparation. The cell contains a fume hood; two 1.3 cu-ft explosives rated Friction-Aire® fuels ovens and an electronic scale for weighing propellant ingredients.

***Cell 8***.

Oxidizer preparation. The cell contains a fume hood, two explosives rated oxidizer/vacuum ovens and two electronic scales for weighing propellant ingredients.

***Cell 9.***

Propellant viscosity measurement and low temperature propellant ingredient storage. The cell contains a rotary viscometer and explosives rated refrigerator.

***Cell 10.***

Propellant conditioning and curing. The cell contains an explosives rated temperature and humidity controlled environmental chamber.

***Cell 11.***

Test sample preparation cell. The cell contained three work benches and an electronic scale for weighing samples.

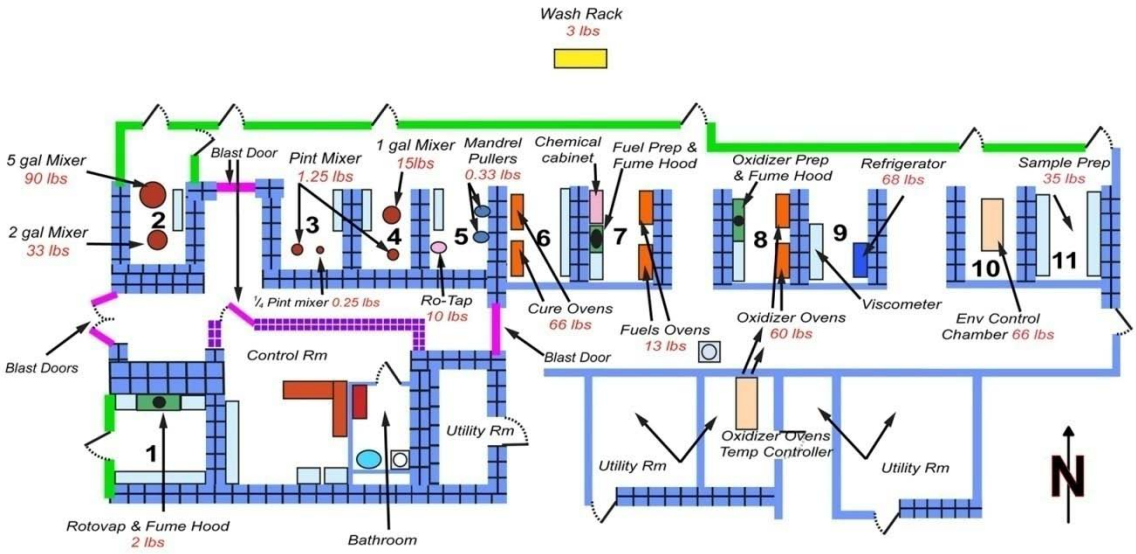


**Figure 3. Bldg 8473 Post-Renovation Layout**

## Bldg 8473 Re-Siting Lessons Learned

There were many lessons RZ-West learned from the re-siting efforts of Bldg 8473. The five main lessons that may prove useful to other DoD organizations faced with re-siting explosive facilities are listed below and will covered in greater detail in the next section of the paper.

1. Determine if re-siting of the explosive facility is required.
2. If re-siting is required, hire a nationally recognized consulting firm that specializes in: developing, assessing and modifying DoD explosive facility site plans.
3. Ensure adequate resources are available to complete the task before starting the effort.
4. Ensure all facility engineering and as-built drawings are available.
5. Ensure the primary stakeholders are involved with providing inputs, reviewing the findings and communicating effectively with each other.

### *Is Re-Siting of the Explosive Facility Required?*

Unless there have been major changes to the facility, mission or operations that would affect QD or renovations/additions that have the changed the facility's structural integrity, re-siting of the facility is most likely not required.

Re-siting an explosive facility requires review/approval from multiple organizations and can take from six months to years to get final DDESB approval. The site plan for Bldg 8473 was submitted into the review cycle on 29 May 2008 and is currently being reviewed by DDESB.

In addition to the time involved with re-siting, the costs associated with re-siting can range from tens of thousands of dollars for a straightforward re-siting without significant consulting support and facility modifications, to millions of dollars if major facility modifications are required.

Another very important consideration is the potential reduction or elimination of explosive quantities for a given location/operation. Changes in regulations, facilities and operations that effect QD values for inhabited building distances (IBD) or public transportation routes (PTR) can significantly lower or eliminate explosive quantities for a given location/operation. This reduction in explosive quantities occurred for several locations in Area 1-30A. The greatest reduction for Bldg 8473 was Cell 1, which was originally sited for 25-lbs of HD 1.1 and re-sited for 2-lbs of

HD 1.1 materials. The elimination of explosive operations occurred in two widely used 1-30A locations, Bldg 8472 that was used as the control room for remote operations in Cells 25-27 (Bldg 8472) and for Pad 44 operations. The other explosive location eliminated as a result of the re-siting effort was the blast pit located on Pad XA used to conduct small-scale card gap testing.

Given the potential time and expense involved with re-siting and the potential reduction or elimination of explosive quantities; the decision to proceed with re-siting an explosive facility should be made only after considering all the associated issues and opportunities involved. A method that has been used with great success in academia and industry to identify an optimal solution for issues and opportunities is the nine-step Problem Based Learning approach:

- Step 1: Describe the Situation
- Step 2: Defining the Problem
- Step 3: Defining End State Goals
- Step 4: Developing Alternative Solutions
- Step 5: Analysis of Alternative Solutions
- Step 6: Risk Assessment and Mitigation
- Step 7: Select the Final Solution
- Step 8: Develop the Implementation Plan
- Step 9: Identify the Measures to Evaluate the Plan and Its Impact

***If Re-Siting of the Explosive Facility is Required***

If re-siting is required, hire a nationally recognized consulting firm that specializes in developing, assessing and modifying DoD explosive facility site plans. Additional desirable capabilities include a thorough knowledge of protective structures design, blast and explosive effects, risk assessment/ management, process safety management (PSM) and explosives storage/operations.

The re-siting of Bldg 8473 involved three main consulting firms, however, the decision to use three firms was driven by factors such as an existing contract to work from, recommendations and the availability of the consultants. There are several firms that offer the complete range of services mentioned above.

The most important consideration is that the consultant(s) can integrate the siting survey information into the structural and hazard analysis of the facility and equipment to provide:

- An accurate hazard analysis of the planned operations
- Real time communications to resolve questions/issues
- Mitigation options of facility/equipment issues

***Ensure Adequate Resources are Available***

As stated previously, the re-siting process can be very costly and time consuming, therefore, it is essential that adequate resources are available including: funding, consultants/support organizations and time.

Another important consideration is the potential for down time if facility modifications are required to resolve siting issues. When the Energetic Materials Research and Characterization Laboratory (Bldg 8475) in Area 1-30A was undergoing renovation, many operations conducted in this facility were able to be relocated to other facilities at RZ-West, however, this was not the case with Bldg 8473. Because of the scope of the Bldg 8473 renovation and the resources available, Area 1-30A has been unable to mix solid propellant for over four years.

If the organization's mission, obligations or commitments cannot tolerate a prolonged down time and suitable facilities are not available to relocate the operations, this must be a deciding factor when considering re-siting or major renovations. Again, the nine-step Problem Based Learning approach can be used to identify an optimal solution.

***Ensure All Facility Engineering and As-Built Drawings are Available***

In order to perform an accurate siting survey and detailed structural, blast, thermal and fragment hazard analysis of the planned operations, it is very important to have all available facility engineering and as-built drawings. Having the dimensions and material specifications available will greatly expedite the siting and hazards analysis process by eliminating the need for supplemental analysis and testing. Some examples include: concrete strength and thickness, rebar thickness, grade and configuration and steel thickness, grade and configuration. When the structural hazard analysis was performed on Bldg 8473, the exact specifications for the concrete used in the blast walls was unavailable. This prompted the need to have core samples taken and analyzed to validate the blast walls met the strength requirements.

***Ensure the Primary Stakeholders Are Involved With Providing Inputs and Reviewing the Findings***.

In order to perform an accurate siting survey and detailed hazard analysis of the planned operations, it is essential to have the primary stakeholders available to provide inputs and review the findings. Primary stakeholders include: the operators and users of the facility, management and support personnel.

The operators of the facility are the most important for providing inputs regarding technical information, area processes, day to day operations and future operations and providing real time communications to resolve questions and issues. The users of the facility (that depend on the availability of the products and services from the facility) also need to provide inputs and reviews of the findings and are important for determining the present and future needs and potential impact to operations. Management inputs and reviews of the findings are important for providing advice, planning, financial support and helping with unforeseen problems.

Support personnel from the safety department, the fire department and civil engineering are also needed to provide guidance with safety, fire and infrastructure regulations/requirements. The Explosives Safety office started the process for re-siting the RZ-West explosive facilities and was actively involved throughout the siting process. The fire department was also actively involved in the siting and subsequent renovation efforts and was the approval authority for all designs and modifications to the fire detection and suppression systems. For AFRL, civil engineering (CE) is responsible for maintaining the real property facilities and infrastructure and the organization provided inputs and reviews of all of the siting survey findings that affected their facilities and infrastructure.

## Bldg 8473 Renovation Lessons Learned

The lessons RZ-West learned from the renovation efforts of Bldg 8473 in most cases mirror those of the re-siting effort. The six lessons that may prove useful to other DoD organizations faced with renovating explosive facilities are listed below and will covered in greater detail in the next section of the paper.

1. Use the nine-step Problem Based Learning approach to determine if renovation is required and to identify an optimal solution.

2. Determine if the proposed renovation will drive additional requirements.
3. If renovation is decided upon, hire a nationally recognized construction firm that is knowledgeable in renovating DoD explosive facilities.
4. Ensure adequate resources are available to complete the task before starting the effort.
5. Ensure all facility engineering and as-built drawings are available.
6. Ensure the primary stakeholders are involved with providing inputs, reviewing the proposed facility designs and equipment and communicating effectively with each other.

***Determine if the Renovation is Required***

Using the nine-step Problem Based Learning approach can be an effective tool for identifying the problem, defining the end state goals, developing alternative solutions, analyzing alternative solutions and performing risk assessment and mitigation. After these steps have been completed, the determination to renovate, or not, can be made. If renovation is decided upon, an implementation and monitoring plan can be developed.

A very important part of the nine-step process is Step 6: Risk Assessment and Mitigation. In this step, all of the potential risks that negatively affect cost and schedule must be identified and mitigated. One of the factors that can have a profound affect to cost and schedule is covered in the next section.

***Determine if the Proposed Renovation Will Drive Additional Requirements***

It is very important to determine if the proposed renovation of the explosive facility will drive additional requirements such as:

- Explosive re-siting
- Complying with new building codes
- Safety and environmental regulations

The renovation of Bldg 8473 drove additional requirements in complying with new building codes and safety and environmental regulations. The fire department required modifications to the fire detection and sprinkler systems; licensed contractors were required to perform abatement of asbestos containing floor tiles/mastic and lead based paint; the new lab hoods required air permit modifications; and the addition of the 5-gal mixer increased the personnel protection and structural requirements that required building the hardened control room.

The most costly (and time consuming) renovation driven additional requirement for Bldg 8473 was the hardened control room. The construction and equipment costs to date are over $250,000. The main construction of the control room wall began in early January 2009 and was completed in early February 2009. The installation of the associated equipment, programming of the data acquisition systems and PLCs and systems checks is still ongoing and is expected to be completed by September 2010.

***Ensure Adequate Resources are Available***

As stated in the previous section, the renovation process can be very costly and time consuming; so it is essential that adequate funding, personnel and time are allocated for the project. With any major renovation effort there is always the potential for cost growth and time delays due to unforeseen circumstances. Therefore, it is important to have a contingency plan such as a management funding reserve to cover unexpected cost overruns due to: schedule slips, increased material costs, increased labor costs, additional requirements and technical challenges.

Another important aspect of the renovation process is time allocation. The contracted renovation efforts for both Bldg 8473 and Bldg 8475 were months behind schedule due to factors such as the coordination, review and approval cycles of documents, work plans, designs and drawings. The in-house renovation efforts took over four years to complete due to labor shortfalls.

***Ensure All Facility Engineering and As- Built Drawings are Available***

As when performing an accurate siting survey and hazard analysis of the planned operations, it is crucial to have all available facility engineering and as-built drawings when renovating an explosive facility.

Having the dimensions and material specifications readily available will greatly expedite the renovation process by eliminating the need for searching for achieved drawings or performing supplemental analysis and testing. In addition, having the as-built drawings can reduce the review, inspection and approval times of support organizations such as: the safety department, the fire department and civil engineering.

***Ensure the Primary Stakeholders Are Involved With Providing Inputs and Reviewing the Proposed Designs and Equipment***

In order to perform an efficient facility renovation, it is essential to have the primary stakeholders available to provide inputs and review the proposed facility designs and equipment. The operators of the facility are the most important for providing inputs regarding technical information, area processes, day to day operations, future operations and providing real time communications to resolve questions and issues.

The users of the facility are needed to provide inputs and reviews of the proposed facility designs/equipment and are important for determining the present and future needs and potential impact to operations while the facility is being renovated.

Management inputs and reviews of the renovation effort are important for providing advice, planning, financial support and allocating resources to help with unforeseen events

Support personnel from the safety department, the fire department and civil engineering are also needed to provide guidance, review, inspection and approval with safety, fire and infrastructure regulations/requirements.

## CONCLUSIONS

The ISA comprehensive siting survey and AES detailed structural, blast, thermal and fragment hazard analysis for Bldg 8473 identified several discrepancies and served as the impetus for a renovation effort to mitigate all of the discrepancies, provide Area 1-30A researchers with state-of-the art sustainable facilities and equipment that are fully compliant with all regulatory requirements and provide the utmost in personal protection.

As a result of the re-siting and renovation efforts for Bldg 8473, over $800,000 has been spent to date and the facility has been non-operational for over four years. When considering re-siting or renovating explosive facilities, the organization’s mission, obligations or commitments must be considered. If there is the possibility of a prolonged down time and suitable facilities are not available to relocate the operations, this must be a deciding factor when considering re-siting or renovating.

The intent of this paper was to document the re-siting and renovation approach/efforts performed by AFRL personnel, consultants and contractors and the lessons learned that may help other organizations faced with re-siting and renovating explosive facilities.

## RECOMMENDATIONS

There were many lessons learned from the re-siting efforts of Bldg 8473. Hopefully some the five main recommendations listed below will prove useful to other DoD or contractor organizations faced with re-siting explosive facilities.

1. Use the nine-step Problem Based Learning approach to determine if re-siting of the explosive facility is required.
2. If re-siting is required, hire a nationally recognized consulting firm that specializes in developing, assessing and modifying DoD explosive facility site plans and can integrate the siting survey information into the structural and hazard analysis of the facility and equipment to provide:
    - An accurate hazard analysis of the planned operations
    - Real time communications to resolve questions/issues
    - Mitigation options of facility/equipment issues
3. Ensure adequate resources (funding, consultants/support organizations and time) are available to complete the task before starting the effort. If the organization's mission, obligations or commitments cannot tolerate a prolonged down time and suitable facilities are not available to relocate the operations, this must be a deciding factor when considering re-siting.
4. Ensure all facility engineering and as-built drawings are available.
5. Ensure the primary stakeholders are involved with providing inputs, reviewing the findings and communicating effectively with each other.

The lessons learned from the renovation efforts of Bldg 8473 in most cases mirror those of the re-siting effort. The six main recommendations include the following:

1. Use the nine-step Problem Based Learning approach to determine if renovation is required and to identify an optimal solution.
2. Determine if the proposed renovation will drive additional requirements.
3. If renovation is decided upon, hire a nationally recognized construction firm that is knowledgeable in renovating DoD explosive facilities.
4. Ensure adequate resources (funding, manpower, consultants/support organizations and time) are available to complete the task before starting the effort. If the organization's mission, obligations or commitments cannot tolerate a prolonged down time and suitable facilities are not available to relocate the operations, this must be a deciding factor when considering major renovations. If possible, have a management reserve to cover potential cost overruns.
5. Ensure all facility engineering and as-built drawings are available.
6. Ensure the primary stakeholders are involved with providing inputs, reviewing the proposed facility designs/equipment and communicating effectively with each other.

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# AFRL Solid Propellant Laboratory Explosive Siting and Renovation Lessons Learned

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# AFRL Solid Propellant Laboratory (Bldg 8473) Background

- **Bldg 8473 built in 1960**
  - Six reinforced concrete cells, explosion-resistant viewing windows , blow-off roof and blow-out back wall
  - Solid propellant mixing, casting, curing, conditioning and sample preparation
- **Renovated in 1965**
  - Added five reinforced concrete cells (Cells 1-5) with explosion-resistant viewing windows, reinforced concrete ceilings and blow-out back walls
  - Cell 1 used as a lab for ingredient preparation and conditioning
  - Cells 2-4 used for mixing, casting and curing
  - Cell 5 used for oxidizer preparation
- **Last re-sited in 1985**

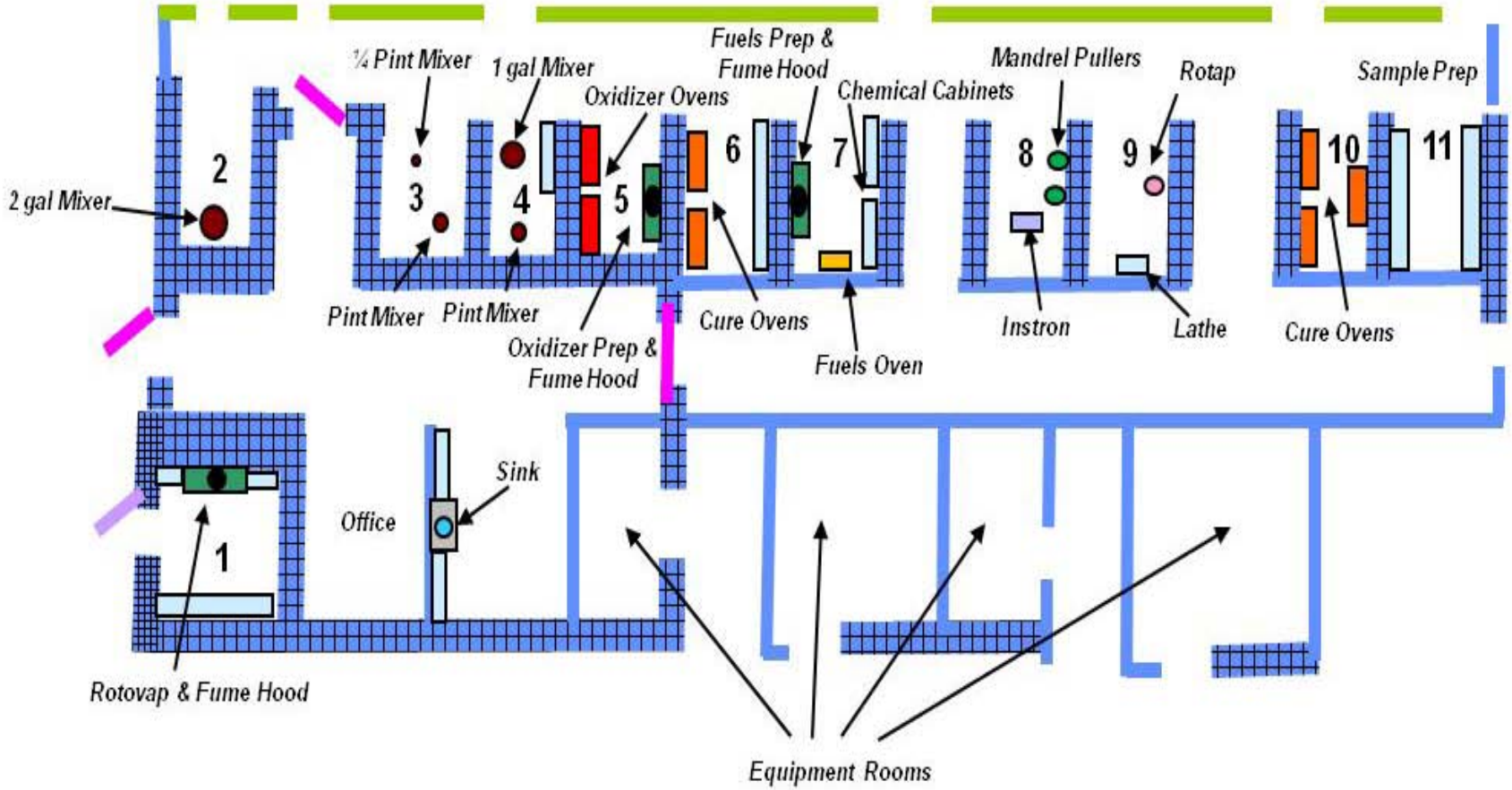
# Re-Siting Effort

- **In 2006 the AFRL (RZ-West) Safety office started re-siting several RZ-West explosive facilities**
- **RZ-West Safety personnel and senior management had the following concerns:**
  - Bldg 8473 was in need of significant renovation
    - Lack of grounding wires and GFI in the facility's electrical circuits
    - Non-compliant electrical fixtures
    - Deteriorating roof, flooring, electrical, plumbing and support equipment
  - Over the 21 year period since the last explosive siting, Bldg 8473 was no longer compliant with current DDESB requirements
    - Non-compliant LPS
    - No TVSS
    - Inadequate personnel protection

# Re-Siting Risk Mitigation

- **To help ensure the re-siting went smoothly, the following approach was implemented:**
  - Renovation of Bldg 8473 was planned that included:
    - New laboratory equipment, hoods, benches, cabinets, conductive floors and electrical and plumbing upgrades
  - Integrated Systems Analysts (ISA) Inc. was contracted to perform a comprehensive siting survey for Bldg 8473
  - Applied Engineering Services (AES) Inc. was contracted to perform a detailed structural, blast, thermal and fragment hazard analysis for Bldg 8473
  - A new Operations Manager was assigned to provide coordination, guidance and review of all re-siting and renovation efforts

# Bldg 8473 Pre-Renovation Layout/Operations



# ISA Siting Survey of Bldg 8473

- **ISA's survey in conjunction with the AES hazard analysis**
  - To determine the appropriate siting values based on the structural and hazard analysis of the facility
- **ISA asked to site all 11 cells for HD 1.1 propellants**
  - TNT equivalence of 125% used for all explosive assessments
  - An increase was requested in Cell 2 from 33 to 90 pounds of HD 1.1 to accommodate a 5-gal mixer
- **Survey confirmed the facility and non-facility issues identified by RZ-West explosives safety**
- **Survey determined explosive quantities would need to be reduced for many of the cells in the facility**
  - From 650 to 426 pounds of HD 1.1 materials (for entire building)
  - From 25 to 2 pounds of HD 1.1 materials (for Cell 1)

# AES Structural and Hazard Analysis of Bldg 8473

- **AES structural/hazard analysis in conjunction with the siting survey and renovation effort to:**
  - Provide an accurate structural and hazard analysis of the facility and equipment
  - Provide an accurate hazard analysis of the planned operations
  - Provide real time communications to resolve questions and issues
  - Mitigate facility/equipment issues through renovation efforts in real time
- **AES identified three main categories of potential issues associated with the explosive quantities requested:**
  - Wall failure
  - Spalling/breaching of the wall
  - Fragments exiting the cells for some operations

# Naval Facilities Engineering Service Center (NAVFAC ESC) Analysis

- **NAVFAC ESC analysis provided mitigations for the AES identified deficiencies**
  - The favored approach was to construct a hardened control room to protect personnel using existing structures in Bldg 8473
    - The first option considered Cell 1 because of the following:
      - 16-in thick reinforced concrete walls on three sides, 10-in thick reinforced concrete ceiling and separate outside entrance
    - The second option considered the office area because of the following:
      - 16-inch thick reinforced concrete walls on three sides, 10-inch thick reinforced concrete ceiling
      - Larger floor space
      - Potential for increasing floor space
      - Internal entrance and potential for second outside entrance
      - No loss of Cell 1 operations
    - **The second option was selected**

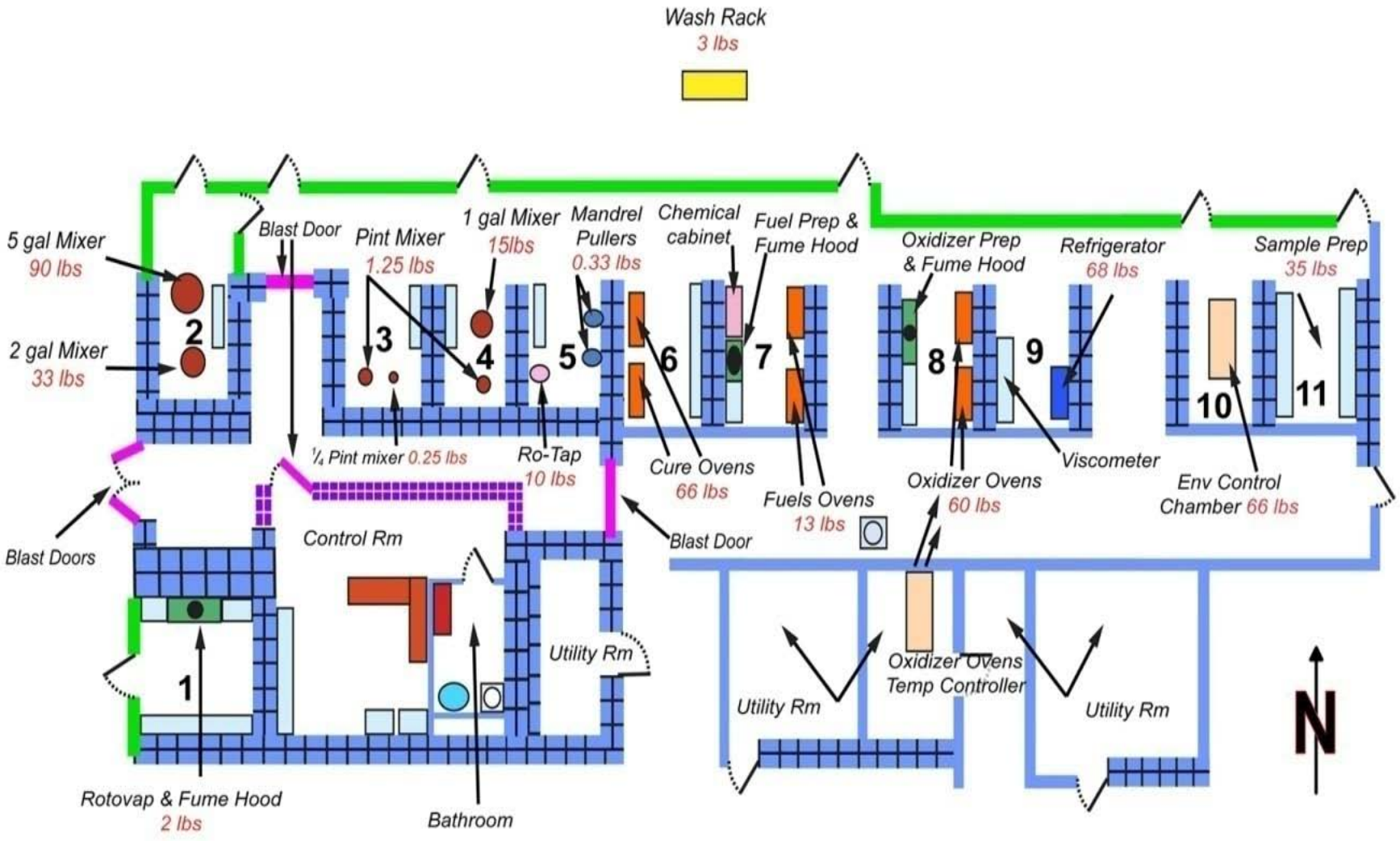
# Hardened Control Room

- **NAVFAC ESC contract expanded to include a preliminary design of a hardened control room:**
  - 8-inch reinforced concrete wall composed of 4 ksi concrete
  - #4 bars spaced at 12 inches on center each way for each face, anchored into the existing reinforced concrete walls
  - 3 psi rated blast door
- **AES provided a detailed design with NAVFAC ESC inputs**
- **The NAVFAC ESC engineering analysis determined all the issues AES identified for Cells 1-11 would be mitigated by:**
  - Requiring personnel to conduct remote operations from inside the hardened control room with the blast door closed
  - All other Bldg 8473 occupants maintain minimum standoff distance from explosive operations

# Bldg 8473 Renovation Activities

- **Construction activities**
  - New conductive floors in the cells and connecting hallways used in explosive operations
  - New roof
  - Electrical and plumbing upgrades
  - New control room and restroom
  - Firex system upgrades
- **New equipment installation activities**
  - New laboratory furniture/equipment: (hoods, benches, cabinets, temperature circulators)
  - New explosives rated cameras, ovens, environmental chambers and refrigerator
  - New computers, monitors, data acquisition systems, programmable logic controllers (PLCs), remotely operated valves (ROVs) and variable frequency drives (VFDs)

# Bldg 8473 Post-Renovation Layout/Operations



# Bldg 8473 Re-Siting Lessons Learned

- **Determine if re-siting of the explosive facility is required**
  - Unless major changes (facility, mission or operations) have been made affecting QD or personnel protection
    - Re-siting of the facility is most likely not required
  - Costs and time associated with re-siting must be considered
    - >6 Months and tens of thousands of dollars for a straightforward re-siting without significant consulting support
    - Years and millions of dollars if major facility modifications are required.
  - Another very important consideration is potential reduction or elimination of explosive quantities for a given location/operation
    - Changes in regulations, facilities and operations that effect QD values for inhabited building distances (IBD) or public transportation routes (PTR) can significantly lower or eliminate explosive quantities for a given location/operation

# Bldg 8473 Re-Siting Lessons Learned (cont)

- **If re-siting is required**
  - Hire a nationally recognized consulting firm that specializes in:
    - Developing, assessing and modifying DoD explosive facility site plans
- **Ensure adequate resources are available to complete the task before starting the effort**
  - Funding, consultants/support organizations and time
- **Ensure facility engineering/as-built drawings are available**
  - Having dimensions and material specifications available will greatly expedite the process by eliminating the need for analysis and testing
- **Ensure the primary stakeholders are involved with:**
  - Providing inputs
  - Reviewing the findings
  - Communicating effectively with each other

# Using the Nine-Step Problem Based Learning Approach to Identify an Optimal Approach

- **Given the time, expense and potential impact to operations involved with re-siting and renovating explosive facilities**
  - The decision to proceed should be made only after considering all the associated issues and opportunities involved
- **The nine-step Problem Based Learning (PBL) approach used in academia and industry to identify an optimal solution for issues and opportunities**
  - Step 1: Describe the Situation
  - Step 2: Defining the Problem
  - Step 3: Defining End State Goals
  - Step 4: Developing Alternative Solutions
  - Step 5: Analysis of Alternative Solutions
  - **Step 6: Risk Assessment and Mitigation**
  - Step 7: Select the Final Solution
  - Step 8: Develop the Implementation Plan
  - Step 9: Identify the Measures to Evaluate the Plan and Its Impact

# Bldg 8473 Renovation Lessons Learned

- **Use the nine-step PBL approach to determine if renovation is required and to identify an optimal solution**
- **Determine if the renovation will drive additional requirements**
  - Re-Siting, complying with new building codes, safety and environmental regulations
- **If renovation is decided upon, hire a nationally recognized construction firm that is knowledgeable in renovating DoD explosive facilities**
- **Ensure adequate resources are available to complete the task before starting the effort**
- **Ensure all facility engineering and as-built drawings are available**
- **Ensure the primary stakeholders are involved with:**
  - Providing inputs
  - Reviewing the proposed facility designs and equipment
  - Communicating effectively with each other

# Conclusions

- **The ISA siting survey and AES structural/hazard analysis served as the impetus for renovations to:**
  - Mitigate all of the discrepancies
  - Provide Area 1-30A researchers with state-of-the art sustainable facilities/equipment
    - Fully compliant with all regulatory requirements
    - That provide the utmost in personal protection
- **When considering re-siting or renovating explosive facilities**
  - The organization's mission, obligations or commitments must be considered
  - If there is the possibility of a prolonged down time and suitable facilities are not available to relocate the operations
    - This must be a deciding factor when considering re-siting or renovating

# Recommendations

- **Use the nine-step PBL approach to determine if re-siting or renovation is required**
- **If re-siting is required, hire a consulting firm that specializes in:**
  - Developing, assessing and modifying DoD explosive site plans
  - Integrating the siting survey information into the structural and hazard analysis of the facility and equipment to provide:
    - An accurate hazard analysis of the planned operations
    - Real time communications to resolve questions/issues
    - Mitigation options of facility/equipment issues
- **If renovation is decided upon, hire a construction firm knowledgeable in renovating DoD explosive facilities**

# Recommendations (cont)

- **Ensure adequate resources are available to complete the task before starting the effort**
  - funding, consultants/support organizations and time
- **If the organization cannot tolerate a prolonged down time, or if, suitable facilities are not available to relocate the operations**
  - This must be a deciding factor when considering re-siting or renovating facilities
- **Ensure all facility engineering and as-built drawings are available**
- **Ensure the primary stakeholders are involved with:**
  - Providing inputs
  - Reviewing the findings or proposed facility designs/equipment
  - communicating effectively with each other